SOME OPPORTUNITIES FOR ASTRONOMICAL WORK WITH INEXPENSIVE APPARATUS.

A Lecture delivered by Professor George E. Hale, Director of the Mount Wilson Solar Observatory of the Carnegie Institution of Washington, at the Royal Astronomical Society, Burlington House, London, W., on Wednesday evening, June 26, 1907. (Plate 5.)

I have sometimes heard it said that the great cost of modern observatories tends to discourage workers with small instruments—observers who are no less interested in the pursuit of astronomical research than the astronomers in the large institutions. It seems to me that if there is any serious discouragement, due to this cause, of men who are engaged in original research with small telescopes and inexpensive apparatus, it is a question whether large observatories should be established. For at any period in the progress of observational astronomy there are two most important subjects for consideration. One relates to the accomplishment of a great amount of routine observation and the discussion of results, and the other relates to the introduction of new ideas and to the beginnings of the new methods which will make the astronomy of the future. I think we will all admit that the introduction of new ideas is quite as important as the prosecution of routine research; and that if any cause whatsoever tends to discourage the men from whom the new ideas might be likely to proceed, that cause of discouragement should be set aside if possible. And therefore I say, with all seriousness, that it is a fair question whether large observatories, with powerful instrumental equipment, should be established if they tend to keep back the man who is pursuing the subject with less expensive appliances, and is introducing, through his careful consideration of the possibilities of research, the new methods which in the process of time will take the place of the old ones. I think it can be shown, however, that the large observatories should be a help rather than a hindrance, at least by suggesting new possibilities of research, in which most valuable results can be obtained by simple means.

I am talking to-night, in purpose at least, to the amateur; but my definition of the amateur is perhaps a broader one than is generally accepted. According to my view, the amateur is the man who works in astronomy because he cannot help it, because he would rather do such work than anything else in the world, and who therefore cares little for hampering traditions or for difficulties of any kind. The "amateur," then, is the person to whom I wish to address my remarks, whether he be connected with a small observatory in the capacity of professional astronomer, or working by himself with very simple instrumental means. But in speaking to the amateur I do not wish to deal with work that shall be satisfactory merely from the standpoint of instruction or

amusement. That is not my purpose. If it is possible to carry on research by simple means that shall really be important and useful, it is my hope to point out some such possibilities. But I do not wish to speak of any work except that of the first class, nor to recommend that any investigations should be undertaken with simple instruments that are not quite as important as other investigations which can be better undertaken with more expensive instruments.

The problem then becomes one of this character—to determine the relative advantages of large and small telescopes for different classes of research, and the possibility of constructing really powerful instruments at moderate expense. I cannot pretend to discuss all phases of this large problem; I shall mention only a few of them, and approach it from a single direction. But before taking up the details of this discussion, perhaps I may be permitted to say that the conception that is sometimes formed of the newer observatories, the idea that vast sums of money are expended, perhaps without the fullest sense of economy, is not always well-founded. For I am quite sure that if you would visit us (to take a single concrete case) in California, you would agree that we have considered the economical side of the question, that we have perhaps in some instances gone almost too far in our desire to save money for instruments of research, and to economise in certain directions where money can be saved. For example, you would find that our offices, our buildings, are of the simplest and least expensive character, while our instruments and machinery are as effective as we can make them. The great expense of such an observatory as the Solar Observatory on Mount Wilson does not depend in large degree on the cost of the instruments used for investigations of the Sun, but in surmounting the difficulties encountered in utilising a mountain site, deprived of the ordinary means of transportation, and in the construction of large equatorial reflecting telescopes for stellar work, which cannot be built cheaply if they are to be really efficient.

I wish now to come to the question before us, and to illustrate some of the advantages and some of the disadvantages of large and small instruments. Perhaps you will permit me, in showing the first slide on the screen, to say that I have some right to undertake a discussion of this sort, because I have viewed the subject from the standpoint of the man using small and inexpensive apparatus. In my first spectroscopic work, which was done in a room in my father's house, the instruments were of the simplest character, and largely of my own construction. Later, a small building was constructed for a concave grating of 10 feet focal length, and the apparatus, although powerful, was not expensive. Subsequently a tower and dome were added, and a 12-inch telescope was erected for photographic work upon the Sun. After the preliminary experiments had been completed, and the spectroheliograph had begun to take form, the possibility that its results could be greatly improved through the use of a larger telescope suggested itself, and

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for this reason I made many efforts to acquire a large instrument for these solar investigations. The result, through the generosity of Mr. Yerkes, was the 40-inch Yerkes telescope, which proved to be very useful for the extension of the spectroheliograph work. The next slide shows the instrument, which you will see is a large and expensive machine. The question, then, comes right down to this point: What are the advantages of such a telescope compared with, let us say, a 6-inch equatorial or possibly a 4-inch equatorial? Is it possible with a 6-inch equatorial to do work comparable in importance with the work that can be done with a 40-inch equatorial?

The next slide will show that there was an advantage in passing from the Kenwood 12-inch to the Yerkes 40-inch, at least for the photography of the Sun. Very minute details of the flocculi were brought out which had not previously been known. But it may easily be shown that the advantages of the 40-inch telescope for most classes of solar work are due more particularly to its great focal length than to its large aperture.*

Let us take another illustration. Here we have a picture of the Moon made by Professor Ritchey with the 12-inch Kenwood telescope. You will notice that near the terminator is the crater Theophilus, which you will see again in the next slide as photographed with the 40-inch telescope. This photograph taken by Professor Ritchey is probably as good a photograph of the Moon's surface as has yet been made, and in this case the advantage of the 40-inch telescope is apparent.† But if we take another case, as illustrated in the next slide, it becomes obvious enough that for certain classes of work the Yerkes telescope is not well suited. Here is a picture made with the 40-inch of the Andromeda Nebula. You see how little it shows, since a long-focus telescope, unless of very great aperture, is not well adapted for the photography of faint nebulæ. When we compare this picture with the next one, made by Professor Ritchey, with the 2-foot reflector (of 8 feet focal length), we appreciate immediately that the 40-inch, in spite of its great advantages for certain classes of work, is wholly unadapted for other investigations. As you know, a refractor of much smaller aperture and of shorter focal length would also give a photograph of the Andromeda Nebula far superior to anything that could be taken with the 40-inch.

If we look at the next slide, which shows Professor Barnard's 10-inch Bruce telescope when it was mounted on Mount Wilson, where he was using it to photograph the Milky Way, you will see an instrument that is very small and inexpensive as compared with the Yerkes telescope. It has a 10-inch Brashear lens of 50 inches

* So far as resolving power is concerned, an aperture of 8 inches would be sufficient to permit the smallest known details of the flocculi to be photographed.

† Here, again, the full visual resolving power is not utilised, but the great aperture is of advantage in permitting the large image to be photographed with very short exposures.

focal length and certain smaller cameras attached to the side of the tube. With such an instrument as this, superb photographs of the Milky Way, like the one illustrated in the next slide, can be taken, which are indispensable for investigations on the distribution of stars in this part of the heavens. Excellent work can also be done with a much smaller lens, provided with a very simple mounting.* A fine instance of systematic work with a portrait-lens is afforded by Mr. Franklin-Adams's photographic map of the northern and southern heavens.

It is hardly necessary to recall the fact that the 40-inch could not do this work at all. If we attempted to photograph the Milky Way with it, we might get a very small region on a very great scale, but to give us any notion as to the general distribution of stars in the Milky Way the 40-inch would be a total failure. However, if it were a question of studying some star cluster like the one shown in this slide, which would occupy a very small region indeed of the Milky Way, the 40-inch would enable us to pick out the separate stars, to study their individual phenomena, their changes in light and position, while such work could not be done on photographs taken with a portrait-lens.

I have shown these miscellaneous illustrations for the purpose of emphasising, what is perfectly well known to all of you, that each instrument has its particular fields of work, in which it can accomplish, or permit to be accomplished, various investigations which are not within the reach of other kinds of telescopes. But I now wish to discuss the question somewhat more specifically, and in doing so I shall confine myself almost entirely to observations of the Sun, although one might attack the subject from many other directions. The first point is this. Suppose one has a small telescope of 4 inches or 6 inches aperture and wishes to observe the Sun with it; and let us assume at the outset that he has no attachments whatever in the form of spectroscopes, but that he wishes simply to make direct observations of the Sun: Is there work for such an instrument at the present time? If you will examine the literature of the subject you may perhaps be surprised to find that many years have elapsed since very careful and extensive investigations have been made similar to those of Langley, which may be almost forgotten by many astronomers, but certainly are not forgotten by those of us who follow the Sun and are accustomed to the appearance of the spots when the definition is good. The next slide shows the well-known drawing of Langley's typical sun-spot. You will remember, if you have systematically observed the Sun, that every time the conditions become extremely good, the structure of sun-spots more and more closely resembles this drawing. This is a typical drawing; it does not represent any particular spot; it brings together observations of various spots; but in general the details of a sun-spot look very much

* Professor Barnard has illustrated in the *Astrophysical Journal* some of the admirable results he has himself obtained with a cheap "lantern lens" belonging to an ordinary stereopticon.

indeed like that drawing when the definition is good enough to show them properly. This subject has been greatly neglected for a long time, and it would well repay observers with large or small instruments to observe sun-spots, and to study many of the details of their structure which still remain obscure and difficult to understand.* Of course the question of the resolving power of the instrument must then be considered. A 4-inch telescope, capable of separating objects one second of arc apart, would not do for the very finest details in a sun-spot. According to Langley, the penumbral filaments sometimes exhibit structure considerably smaller than such a telescope would show; but a 10-inch or 12-inch telescope would show everything that has ever been recorded in a sun-spot, and there are many instruments of that size available for such observations.† Even a much smaller telescope, if carefully and systematically used, would contribute largely to our knowledge of sun-spots and of the structure of the solar surface. One might enlarge upon this subject, but time is hardly sufficient to permit me to do so.

Now let us consider the case of the prominences. If we have available a small spectroscope like that admirable little instrument designed by Evershed, or the one made by Thorp,‡ or a still simpler home-made instrument, and attach such a spectroscope to a 4-inch or 6-inch telescope, we have an almost ideal equipment for the observation of the solar prominences. As a matter of fact, an instrument like the 40-inch is wholly unsuited for work of this kind. You will easily see why. If you wish to observe the entire prominence, its image in the focal plane of the 40-inch telescope is usually so large that the slit cannot be opened wide enough to include the prominence without admitting too much light of the sky. Therefore, for a study of the general characteristics of prominences, the small instrument has a great advantage over the large one. It was practically out of the question with the 40-inch for us to do systematic visual work on prominences. When the conditions were peculiarly fine we could study the structure of certain prominences, and I never saw anything more remarkable than such details when they came out under the best seeing. But with the spectroscope available, and under ordinary atmospheric conditions, we could not make records of the general form and distribution of prominences that would compare in value with the records obtainable with small telescopes.

* For example, it would be of great interest to study the structure of the umbra, as seen through a minute pin-hole in the focal plane of a positive eyepiece, as Dawes did many years ago.

† It must not be forgotten that photography is still far behind visual observations in revealing the minute structure of sun-spots. It can hardly be doubted, however, that if only the umbra and penumbra were permitted to fall on the plate, and the exposure properly regulated, new and valuable results would be obtained. The amateur will readily find many opportunities for work in this field.

‡ I wish to call special attention to the solar spectroscopes and other inexpensive instruments made by Mr. Thomas Thorp of Manchester. One of these, a polarising helioscope, has done excellent service on Mount Wilson.

It has remained for certain amateurs here in England very recently to show that objects upon the surface of the Sun which escaped many of the earlier solar observers can be observed at any time when the conditions are favourable with a very small instrument indeed. For example, Mr. Buss and Captain Daunt, and, I believe, some others, have been observing the Sun with such instruments, and have been able to see upon the disk dark regions in which the D_3 line is strengthened, which I think have never been recorded before in a systematic way. Observations of the dark D_3 line upon the face of the Sun were formerly mentioned as unusual and rather remarkable phenomena, and certainly, so far as I have ever seen in the literature of the subject, the dark hydrogen flocculi were never recognised upon the Sun by the earlier spectroscopists; but they are seen, at times at least, by those gentlemen to whom I have referred. This I can make quite certain from my own knowledge, because on one occasion, when Mr. Buss had described one of the very peculiar dark hydrogen flocculi—flocculi of this type appear very much darker than the ordinary ones photographed daily with the spectroheliograph—I looked up our photographs of that date, and there was the image recorded by the spectroheliograph precisely as it had been described. So that if I had previously been a little doubtful as to the possibility of seeing these objects with such an equipment, I gave up all doubt after having made that comparison.* One might say that it would hardly be practicable to observe such phenomena in any satisfactory way with a large telescope. A small one is very much more advantageous for work of this kind. As soon as possible we are going to set up a small equatorial for the purpose of seeing these objects and comparing them with our photographs, after having derived the knowledge of the possibility of observing them from the work done by these men in England. But we will not undertake systematic work in this field, as I hope the valuable observations now in progress here will be continued. No records are made with the spectroheliograph of the D_3 image of the Sun at present. We have tried experiments, but so far they have not been successful. We ought to be able to photograph the Sun through the D_3 line, but we have not done it yet. The only existing records are those made by the members of the British Astronomical Association. These observations should be made in conjunction with other solar observations, as in fact is being done at the present time. The characteristics of the hydrogen lines are being observed at the same time that these D_3 images are being recorded, so that any relationship between the two may be discovered. I cannot dwell upon this very interesting subject. There is a great opportunity here for further work of high importance.

I must now pass to the question of sun-spot spectra. I need hardly tell those who are present that observations of sun-spot

* As I understand the matter, only the more conspicuous dark flocculi can be observed visually.

spectra made visually are sometimes far more valuable than those which can be made by photographic methods. Take, for example, the lines in the green region of the spectrum. This photograph will suffice to show them. Here is the *b* group in the spectrum of a sun-spot and also in the spectrum of the photosphere. We see in the spot a large number of fine lines, long ago observed by Young and Maunder, and now being studied with great care. All of these fine lines shown by a powerful instrument photographically can be seen visually with a small spectroscope attached to a 6-inch or probably a 4-inch telescope, and many other phenomena which cannot be photographed at all can be seen with a similar equipment. There is a certain advantage in observing such spectra with a larger telescope, provided that the spot under consideration is a small one. But if the spot is a fairly large one (and hitherto no one has had time to observe the spectra of small spots systematically), I think there is no advantage whatever in having a large telescope to form the image of the Sun on the slit of the spectroscope; it is merely a question of having an image of moderate dimensions upon the slit, and after that the spectroscope does the work. So that, so far as the spots actually under observation are concerned, a small telescope is quite as satisfactory as a large one for *visual* work on their spectra.

I will return in a moment to the question of the relative advantages of the photographic and the visual method of observing spot spectra; but I want to point out in passing that the 40-inch telescope has certain very definite advantages for work on the Sun. If one wishes to observe the spectrum of the chromosphere, for example, the advantages of great focal length immediately become apparent. The width of the spectroscope slit is essentially constant; the chromospheric arc must have a certain linear width on the slit in order to permit the base of the chromosphere to be observed; and consequently the spectrum of the chromosphere, as seen with the 40-inch telescope, is a remarkable sight, showing thousands of lines which do not come out with a small focal image of the Sun.

Here we have, then, an illustration of the advantages for certain purposes of considerable focal length. I think it is not so much a question of the telescope's aperture here, because we must not forget, in thinking of the optics of this question, that the brightness of the spectrum (for constant purity) is quite independent of the linear or the angular aperture of the object-glass that forms the image of the Sun on the slit of the spectroscope.* Perhaps it is well to bear in mind that the brightest solar spectrum one can get is obtained without any telescope whatever to form an

* When the focal length of the collimator is limited (as is usually the case in a spectroscope attached to an equatorial telescope), an increase in the angular aperture of the telescope permits the linear aperture of the spectroscope, and consequently the resolving power and the brightness of the spectrum, to be increased up to a limit fixed by the size of the grating available. With a cœlostat telescope, however, the same conditions do not obtain, since the aperture of the spectroscope can be increased by merely increasing the focal length of the collimator.

image on the slit, but merely with a collimator of suitable angular aperture. But a large solar image is frequently advantageous, and an equatorial telescope of great focal length is necessarily an expensive instrument. The aperture in the case just mentioned is less important than the focal length; but even if the aperture were only 6 inches and the focal length unchanged, the tube must still be 64 feet long, and the mounting would cost no less than the mounting of the Yerkes telescope. So if we wish to have an instrument of great focal length, and yet keep down the expense to a reasonable figure, we must use a telescope of a different type. There are many other reasons why we should wish to use a fixed telescope for certain kinds of solar work, although I should be the last to admit that the 40-inch telescope is not an almost perfectly satisfactory machine of its kind. It has, as we have seen, inconveniences and disadvantages for some classes of work, but in other fields its superior qualities become more and more striking day after day as the observer learns to appreciate them. I only wish we could afford to have such a telescope (or even a much smaller equatorial refractor) on Mount Wilson, as it would be of great service for many purposes.

Now let us consider some of the possibilities of the fixed telescope; and let me show, for purposes of comparison, a picture on the screen of the Snow telescope which is now employed at Mount Wilson. Here is a cœlostat, with mirror 30 inches in diameter. After passing to a second mirror the light is reflected to a concave mirror of 60 feet focal length, which sends it back and forms a large image of the Sun within a laboratory. This is a very simple instrument indeed. The first cœlostat we set up on Mount Wilson was a small one used by the Yerkes Observatory party at the eclipse of 1900, and it was not originally arranged for work of this kind; so we simply built a wooden support for a second mirror, and with the aid of a 6-inch objective of 60 feet focal length we made a telescope which served admirably for our solar work until this one was put up on the mountain.

The next photograph shows the spectrograph used with the Snow telescope. It is of the Littrow or auto-collimating type, with slit and plate-holder at one end of a long tube and lens and grating at the other. Light from the solar image, after passing through the slit, falls on the lens 18 feet (its focal length) distant. The rays, thus rendered parallel, then strike the grating and are returned to the lens, which forms an image of the spectrum on the photographic plate, just above the slit (the grating being tipped back a little). Such an outfit (fixed telescope and spectrograph) is an extremely simple thing to build in inexpensive form. Cœlostats, for example, are common nowadays for eclipse work. One might have a cœlostat with a mirror only 6 inches in diameter and a second mirror about 4 inches in diameter, and then perhaps a telescope lens of 4 inches aperture and 40 feet focal length. Such an instrument as that, which could be very cheaply built indeed, would give a large solar image, adapted for many kinds of solar work.

Let me show you in the next slide how we build our spectrographs in actual practice. This is the most powerful spectrograph in use in the laboratories of the Solar Observatory. Here is a little slit I bought from Hilger, the last time I was in London, for a few shillings. All other parts of the spectrograph, except a lens and grating, are of wood, built in a few hours by a carpenter.* The wooden support for slit and plate-holder stand on a concrete pier, and close an opening through a partition which forms one end of a narrow dark room. Eighteen feet from the slit, within the dark room, is another concrete pier. A sliding wooden support, carrying a lens, and a simple wooden mounting for the grating, stand on this pier, and complete the spectrograph. Owing to the scarcity of gratings, we are fortunate in being able to use one loaned by Professor Ames, of Johns Hopkins University. If we had no reflecting grating, we could buy a replica very cheaply from Thorp, or Wallace, or Ives,† which would give quite as good photographs as we obtain now (though the exposures would be longer, because of the smaller aperture). They might even be better, because our photographs of spot-spectra (made with the similar spectrograph of the Snow telescope) are not what they ought to be, or what I hope they will subsequently become. They would not stand comparison for a moment, so far as perfection of definition is concerned, with those magnificent photographs of the solar spectrum made by Mr. Higgs in the centre of Liverpool, under conditions which would ordinarily be called very bad even for a crowded city, with tram-cars constantly passing in front of the house. With a spectrograph of his own construction (except the grating), Higgs made the finest photographs of the solar spectrum ever produced; superior, as Rowland would have said, to the best photographs made by himself at the Johns Hopkins University. It is obvious that something other than an expensive instrument is required to make a good photograph. Mr. Higgs has the ability, which others may acquire, to obtain superb definition and exquisite photographs with very simple apparatus indeed.

With a spectrograph of 1 inch aperture and 10 feet focal length, used with a fixed telescope of 4 inches aperture and 40 feet focal length, one would be in a position to make good photographs of the spectra of sun-spots.

What, then, are the relative advantages of visual and of photographic work? The next slide shows some photographs. The upper one is the spectrum of the Sun and the lower one is that of a spot. These photographs are better than visual observations for the determination of the wave-lengths of unknown lines in spot spectra, simply because you can measure the position of a line on

* Except the plate-holder, which is of a standard make.

† As these are not reflecting gratings, the auto-collimating spectrograph might in this case give way to one in which a separate camera lens is used. With the angular aperture here considered, well-made simple lenses would obviously serve perfectly well for collimator and camera, the photographic plate being set at the angle required to bring a sufficient range of spectrum into focus.

the photograph to much better advantage than you can do it visually at the telescope. They are also better for the determination of the relative intensities of the lines, especially the fainter ones. But when you have said that, you have said almost everything that can be said for the photographs, and you have left out of account many of the very important advantages of visual observation. These photographs represent the integrated spot spectrum, as it were. Even with a large image of the spot on the slit of the spectrograph (and you realise here that the principal point of our great focal length is to have a large image of the spot on the slit), we cannot as yet satisfactorily record minute differences in the spectrum corresponding to small details in the spot. If we wish to study these very important differences in the spot, we must do so, at present at any rate, by visual means. For example, Mr. Newall, your President, told me the other day that he had found the spectrum of the outer edge of the penumbra of a spot to have the same characteristic strengthening of the lines that is observed in the umbra, which is a very difficult thing to explain from the standpoint of the hypothesis I have been favouring of late, viz. that the principal cause of the change of the relative intensities of lines in a spot is reduced temperature of the vapours in the umbra. I knew nothing about that; I had not been observing the spot spectrum visually for many years, and in our photographs this phenomenon is not recorded. You see, then, in such a case the decided advantage of visual observations. I might go on to speak of other advantages. For example, suppose there were a sudden change in the spectrum due to an eruption; the chances that one would get a photograph just at that time are small, whereas visual observations necessarily occupy a considerable period of time, during which eruptions might be detected.* Even a few results might be of extreme importance, and would probably be wholly missed in the photographs. Again, the extension of certain lines outside of the spot upon the photosphere is not recorded at all in our photographs, because of the method we usually employ of excluding from the plate all light except that which comes from the umbra, and perhaps part of the penumbra. We ordinarily get no trace of these extensions, but perhaps the conclusions drawn from the study of such phenomena may have much to do with the final views as to the nature of the spots themselves.

To mention only one other thing, the reversals of spot lines which have been seen by some observers have not been photographed with our present apparatus. Whether they can be photographed in the future remains to be seen. But, without going into this subject of spot spectra any more in detail, you will certainly agree that the visual observer has a superb opportunity, which the photographic observer cannot by any possibility take away from him.

* It is, of course, desirable to take photographs as often as possible, since a photographic record of a marked change in the spectrum, if fortunately obtained, may be much more valuable than the results of a few visual observations made hastily.

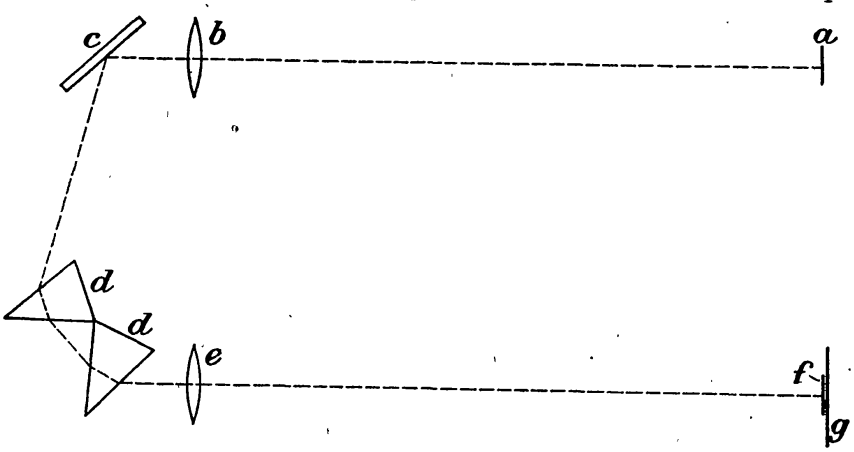
I now wish to speak rather more particularly of another phenomenon mentioned here the other night, which is peculiarly adapted for investigation with a small solar image. I refer to the differences between the spectrum of the centre of the Sun and the spectrum of the Sun's disk near the limb, as shown in the next photograph. Here is the spectrum of the centre of the Sun, and here is the spectrum of the Sun at a point a short distance inside of the limb. You will see at once the remarkable changes that take place. The broad H_1 and K_1 lines (or bands) are greatly reduced in width; and the same thing occurs, I think, in the case of all lines that are accompanied by wings. In this region of the ultra-violet many of these lines have wings, which are lost or greatly reduced near the edge of the Sun. This causes a remarkable change in the appearance of the spectrum. Several other curious things occur. Not only do these wings change in intensity very much, but the central part of the line, which seems to be sharply distinguished from the wings, undergoes a decided change of intensity also, so that we find from a preliminary examination of the plates that the lines that are strengthened in sun-spots are generally strengthened near the edge of the Sun, while the lines that are weakened in sun-spots are generally weakened near the edge of the Sun. This is true, I think, in the great majority of cases. Again, we find another curious thing: almost all of the lines derived from points near the Sun's limb are shifted towards the red in the spectrum with reference to lines from the centre of the disk. But there are some striking exceptions, and one of them is most significant: the lines in this fluting of cyanogen are not appreciably displaced. As we know from laboratory experiments that flutings are not displaced by pressure, whereas lines are thus displaced, we seem to have an interesting confirmation of the conclusion previously reached by Halm from his visual observations of two lines in the red—that the displacement of these lines is to be ascribed to pressure.*

This investigation is a many-sided one, with applications to both solar and stellar phenomena. There is room here for many investigators, who can obtain results quite equal, and very likely superior, in value to any we can get at Mount Wilson. A large image of the Sun is not required, because the effect is very appreciable at some distance from the limb. It is also a matter of no importance whether the definition of the solar image be good or bad. The one essential point is that the spectrograph be fairly powerful, and this is a very simple thing to realise at moderate expense. I hope to see this subject taken up by several observers, who will determine the shifts and the relative intensities of the Fraunhofer lines, seek for evidence of periodic changes, and work out an explanation of these remarkable phenomena which will harmonise with some

* This conclusion is further confirmed by the fact that lines of a given element, which exhibit unequal displacements at a certain pressure in the laboratory, in general show corresponding displacements near the Sun's limb. It remains to be seen, however, whether some other hypothesis may not be equally capable of accounting for the observed phenomena.

explanation of the relative intensities of the same lines in sun-spots and in the spectra of stars.

I may now touch upon another field of solar research, and consider the possibility of doing useful new work with the spectroheliograph, which is by no means so expensive and formidable an instrument as one might suppose. The slide shows the first spectroheliograph used on Mount Wilson, before we built the more permanent one now employed; and since the fact that we did substitute a permanent instrument for the temporary one might lead to the inference that the former did not give good results, I may add that the photographs made with the wooden instrument are even better than the later ones. They show only narrow zones of the solar surface, but for sharpness they have never been surpassed.* In the illustration the spectroheliograph is partly hidden under this spectrograph, and you can only get a rough notion of it. There is a rectangular wooden platform here mounted on a pier.



At each corner of the platform was screwed a small cast-iron block, in which a V-shaped groove had been planed. In each groove was a steel ball. A moving platform, also built of wood, carried the optical parts of the spectroheliograph and rested on these balls, so that it could be moved across the image of the Sun (formed by a cœlostat telescope). The motion was produced by a small electric motor, belted with a piece of fish-line to this large wooden pulley, which drove a screw passing through a lead nut fastened to the movable platform. The screw was cut on a foot lathe and the nut cast on it. This simple mechanism provided the means of producing a slow uniform motion of this upper platform across the image of the Sun. The arrangement of the optical parts was precisely the same as in the Rumford spectroheliograph.

Looking at the instrument in plan, we have a slit here (*a*) through which the light passes. A very simple slit will do. This was an old one; I think it came from a portion of the old Kenwood

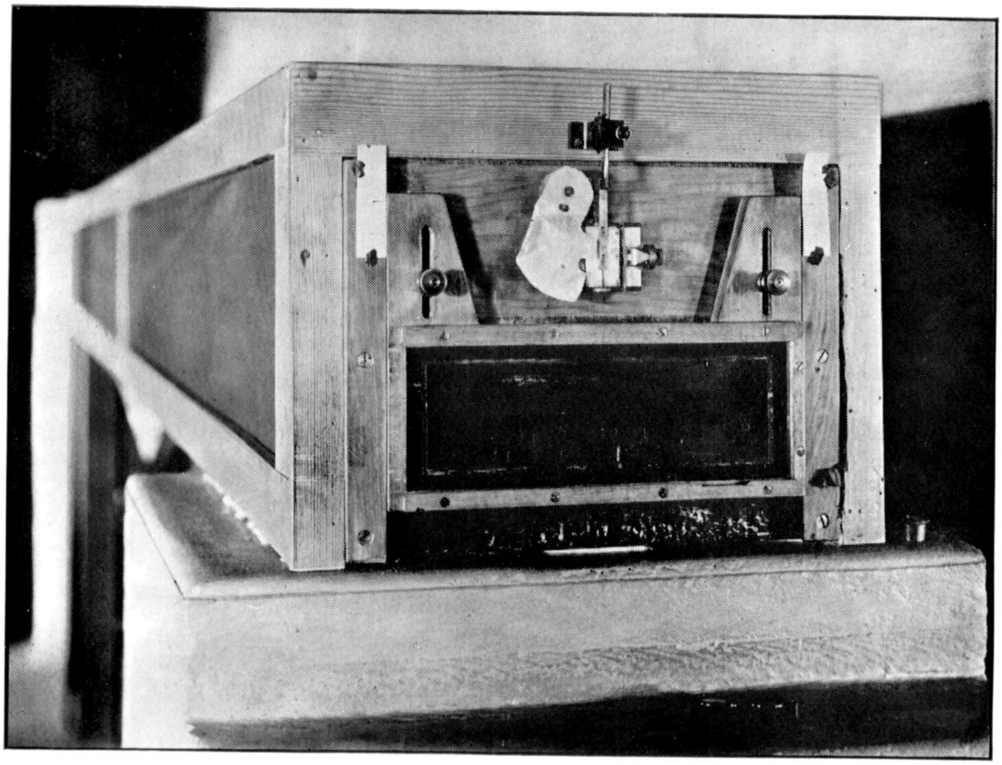
* In the 5-foot spectroheliograph now employed, the dispersion is great enough for photography with the hydrogen as well as the calcium lines. For this reason the exposures are longer, and the definition somewhat less perfect, though quite satisfactory for practical purposes.

spectroheliograph. The light passed through this slit and fell on a collimating lens (*b*), which may be an ordinary uncorrected lens if the focal length is sufficient. We happened to have some achromatics which we used, but they were no better than a simple lens would be. The parallel rays fell on a plane mirror here (*c*), and were reflected to these prisms (*d*, *d*). We used two prisms, but one will do perfectly well, unless hydrogen as well as calcium flocculi are to be photographed. These prisms had been discarded; they were originally made for the Bruce spectrograph, but they were so poor they could not be advantageously used, so we borrowed them from the Yerkes Observatory and put them in here. The two prisms, with the mirror, gave a total deviation of 180°. The light then passed through the camera lens (*e*)—here, also, a simple lens will serve very well—which formed an image of the spectrum on a second slit (*f*), close to the fixed photographic plate (*g*). By setting this slit on the H_2 line of calcium, and moving the instrument slowly across the solar image with the motor, excellent photographs of the calcium flocculi were obtained.

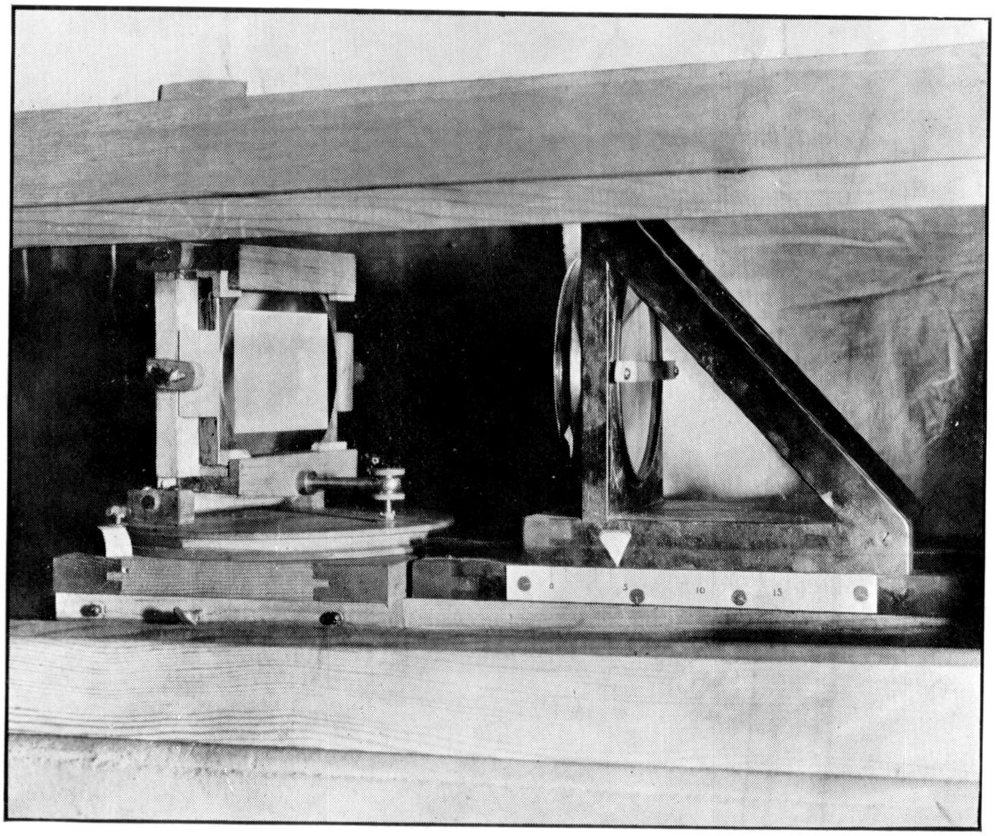
The next slide shows some photographs taken with the permanent instrument. Such photographs as these, made with the calcium and hydrogen lines, open up for investigation a large field, which anyone can enter with just such an equipment as I have described—a very simple instrument, with small prisms and lenses, and built almost entirely of wood.

I will show you in the next photograph some pictures obtained with the wooden instrument. You will notice that in this case the motion was not absolutely uniform; you can detect the slight irregularity of motion, but it did not affect the usefulness of the negatives. This is a direct photograph of the Sun; this is made with the H_1 line of calcium, and this is the same region as photographed with the H_2 line of calcium. If somebody would go to work with such an instrument and let us know exactly what such photographs as these mean, they would at least confer a very great favour upon me, because hitherto I have been unable to determine with certainty the relative parts played by the continuous spectrum of the faculæ and the light of the H_1 line of calcium in producing the photographs. That question is still open, and many investigations will be required to settle it beyond doubt.

In this H_2 photograph we probably have a picture of the calcium vapour at a higher level than the level represented by the H_1 plates. You see, for example, this bridge of calcium vapour across the spot, which is not shown by H_1. Many investigations of great interest could be carried on with such a spectroheliograph as I have described. I wish I had time to go into them; there is only one I may mention, and that is the comparison of the calcium and the hydrogen images. Mr. Butler has asked me to explain to-night a point which I unfortunately failed to make clear in my talk here at the last meeting of the Society. In speaking of the relative level of the calcium and hydrogen flocculi, I said we found that the dark hydrogen flocculi are shifted somewhat towards the



Slit and plate-holder end of simple wooden Spectrograph of Littrow or auto-collimating type (18 feet focal length), used in the spectroscopic laboratory on Mt. Wilson [not the instrument referred to in the lecture, but a similar one, suitable for use in an open room].



Grating and lens supports for modern Spectrograph (18 feet focal length), used in the spectroscopic laboratory on Mt. Wilson. The bar for cutting off reflections from the lens is shown.

[*To face page* 76.

limb of the Sun as compared with the corresponding bright calcium flocculi. The natural conclusion to which I came was that the hydrogen absorption shown in this photograph is produced at a somewhat higher level, amounting to something like 1500 miles, than the calcium radiation which gives us this photograph. Mr. Butler pointed out to me that the photographs of the flash spectrum show the calcium vapour to rise to a higher level than the hydrogen gas, and that the difference is about 1500 miles. There is no question about the validity of this result, and the point is to show that it is compatible with my conclusion. I think the reason is simple enough, and lies in this fact: the flocculi photographed with the H_2 line do not represent the highest calcium vapour, but a level considerably below that; whereas the *absorption* phenomena known as hydrogen flocculi apparently represent the upper hydrogen in the chromosphere, or in some cases the prominences themselves. The level of the hydrogen absorption seems to be about 1500 miles higher than the region from which the H_2 light of calcium proceeds. If, as occasionally happens, the highest calcium vapour in the chromosphere is recorded photographically, it acts as hydrogen does, and gives dark absorption phenomena, due to the high level H_3 line, and not to be confused with the bright calcium flocculi due to H_2. This point is perhaps a minor one, but it illustrates some of the results that can be obtained with a spectroheliograph.

I see that I must rapidly draw to a close. I might mention various other methods of employing spectroheliographs, and if anyone present should be interested at some future time to take them up I shall be delighted to discuss them in detail. I may remark in passing that with a Littrow spectrograph, or any long focus spectrograph, and a fixed solar image, one can undertake other work of various kinds, such as a determination of the solar rotation, along some such plan as Dunér or Halm followed, but using different lines in the spectrum, and benefiting from the advantages of photographic methods. In all such work, co-operation with other investigators is greatly to be desired, because it might otherwise frequently happen that two men would be doing the same thing, whereas it would be just as easy for them to supplement each other's work instead of duplicating it.

One other phase of the subject which I should like to have time to discuss, but cannot, is that of stellar spectroscopy. You will see that for stellar spectroscopy a large telescope in general does have an advantage. The more light one can collect and concentrate in a stellar image the more dispersion can be employed in the spectroscope, and the users of large apertures therefore do have an advantage in stellar spectroscopic work. But the fact remains that small instruments can be used to very great effect in this field also, provided that one intelligently plans his investigations. I know of no better example of this than one which I am permitted, by the kindness of Father Sidgreaves, to illustrate. Here is a photograph of the spectrum of o Ceti, made with a

refractor of 4 inches aperture, with a prism of $22\frac{1}{2}°$ angle placed over the object-glass. The focal length of the telescope is 4 feet.

The slide shows the spectrum of Omicron Ceti on the 29th November 1905 and on the 1st December 1906, and brings out with great clearness the remarkable changes which occurred during that period. If this spectrum had been photographed with such an instrument, let us say, as the Bruce spectrograph of the Yerkes Observatory attached to the 40-inch telescope, there would have been some advantages, but there would also have been some disadvantages, because the entire region covered by the photographs made with that instrument (when three prisms are used) is a limited one here in the blue. All of these remarkable flutings in the less refrangible region would not have appeared in the photographs, and nothing would have been known, if one had been confined with such an instrument to a short region of the spectrum, about the very interesting changes shown in this particular case. The next slide shows another photograph taken by Father Sidgreaves, in this case with a somewhat different instrumental arrangement—a direct vision prism at the focus of a 15-inch equatorial. But you will see the great range of spectrum included on the plate, and remember again that almost all the spectrum, except a very small region, would be missing on photographs taken with such instruments as the Bruce or Mills spectrographs, or other three-prism instruments employed for the investigation of stellar motions in the line of sight. You will notice the remarkably interesting and important fact that the Hϵ line of hydrogen is absent from the picture, probably, as Mr. Newall suggested, cut out by the absorption of the H line of calcium—the broad H_1 band; perhaps in another star lying nearer to us than the star which gives the bright lines of hydrogen. This serves to illustrate the great importance of the work that can be done with an instrument of very small size indeed, even in this field of stellar spectroscopy, which seems peculiarly to belong to telescopes of large aperture. As I said before, in general the investigator with a telescope of large aperture does have an advantage in stellar spectroscopic work; but there are various investigations of this sort—and of the kind Professor Pickering has taken up in his very extensive surveys of the whole sky with objective prisms—which are of extreme importance, and which cannot be replaced by work done with large instruments.

I might go on to speak of the possibilities of work on variable stars, but they are familiar to most of you. The observation of many wide double stars, my friend Burnham tells me, has been neglected since the time of Herschel, because the large instruments, and even the small ones, have been devoted to closer objects, so that in revising his great catalogue Burnham had to measure with the 40-inch a great many wide doubles which had not been looked at perhaps since Herschel discovered them more than a century before. Important double-star work is always open to men with small instruments, if a micrometer is available.

Then I might go on to the case where a man has no telescope at all, and still wants to make contributions to astrophysics. I do not now speak of such splendid work as Anderson did when he discovered Nova Persei with the naked eye; but if one were convinced that the overcast sky of London would never open again, he could still work in his laboratory and make important contributions by identifying lines and bands in spot spectra, as Professor Fowler has been doing of late, or by researches in a score of other fields.

I will close with a few practical suggestions. One reference to the matter of atmosphere. Perhaps some of us feel that if we could only ascend into the upper regions we could get results very much better than are obtainable in London. But if we stop to think of the men who work in London and what they have done, we must recognise the fact that even here the conditions are not so bad as we sometimes imagine. I have often been strongly impressed (since my work in Chicago) with the belief that a smoky atmosphere has some advantages in astronomical work, for it seems that the seeing is frequently improved in solar observations when the sky is smoky. Here is a fine chance to test that question, and I think it has been tested at Greenwich, and that some of the photographs taken there (both solar and stellar) prove that London smoke does not prevent excellent definition. I examined rather carefully some plates there yesterday, and the star images are surprisingly good in many instances. It seems to me that definition by night as well as by day at Greenwich must be of an order much higher than one might suppose when one thinks of Greenwich as being within the boundaries of London. But it is perfectly possible to get good results anywhere, provided sufficient care is taken. One must consider, for example, the best time of day for solar work. It usually happens that the best definition of the Sun occurs in the early morning and the late afternoon. Mr. Newall tells me that this is as true at Cambridge as it is at Mount Wilson. This is worth looking into if one takes up work on the Sun. Further, one must have a definite plan of work. This is of prime importance. Devote your entire attention to a single investigation, involving, if possible, two or three parallel series of observations, so devised as to throw light on one another. Frequently the value of a given series of observations may be enormously enhanced if other observations are available to aid in their interpretation. For example, in studying the spectra of sun-spots, the character of the spots, their motions, and changes of form, and the distribution of the flocculi in their neighbourhood, may be vital factors in interpreting the spectroscopic phenomena. Then, again, there is the great possibility that new methods and new instruments can be applied. Up to the present time I think the interferometers of Michelson or of Pérot and Fabry have never been systematically employed for work on the Sun: that admirable method which Fabry is using at the present time in the determination of absolute wavelengths would perhaps be very useful indeed if applied to the

measurement of the displacement of solar lines at the centre and at the limb. I also believe that the echelon spectroscope has never been used for the observation of the narrow bright lines in the chromosphere. Furthermore, we are always confronted by the possibility of perfecting our optical apparatus. I have been trying for years to get good prisms of large size, but cannot get homogeneous glass, and therefore it now seems necessary to attack the problem of fluid prisms. If someone could take that question up and show us how to make very large prisms that would be essentially perfect, they would accomplish a great advance. Lord Rayleigh told me the other day how he made some large fluid prisms that gave nearly theoretical resolution. By an extension of the same methods it seems likely that still larger prisms, suitable for the exacting requirements of photographic work, could be obtained.

And so I might go on pointing out opportunities of various kinds, but I should tire you if I ventured to do so. We must not forget, however, that the possibility always exists of getting some entirely new method that will be quite as important as any application of the interferometer, or the échelon, or other instruments to which I have called attention.

In concluding, I may add that we have made at the Solar Observatory a few drawings of some of these simple wooden instruments, which I shall be very glad to place at the disposal of anyone who might care to build instruments in a similar way.* They may serve a useful purpose by saving a certain amount of time.

I hope I have shown that it is possible not merely to do work of an inferior quality, but to do work of the first quality, with small or inexpensive instruments; work that cannot be duplicated or will not be duplicated with large instruments; in other words, that there is a splendid field for any man who wishes to accomplish results, wherever he may be situated, and however simple his means of research may be. I feel so strongly on this subject that I hope the suggestions I have made will not be entirely without effect. We need the ideas of men from all parts of the world; we need the contributions they can make; and we need them even more than we need larger instrumental means than we now possess.

* At Mr. Maw's request, a number of blue prints will be sent to the Royal Astronomical Society for convenient reference.

Errata in the Rev. T. E. R. Phillips's paper, Monthly Notices, vol. lxvii.

Page 524, line 8, *for* 1895–6 *read* 1905–6.
Page 526, line 31, *for* 1907 *read* 1906.